A Method to Derive Smoke Emission Rates From MODIS Fire Radiative Energy Measurements

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***Abstract*—Present methods of emissions estimation from satellite data often use fire pixel counts, even though fire strengths and smoke emission rates can differ by some orders of magnitude between pixels. Moderate Resolution Imaging Spectroradiometer (MODIS) measurements of fire radiative energy (FRE) release rates R_{fre} range from less than 10 to more than 1700 MW per pixel at 1-km resolution. To account for the effect of such a wide range of fire strengths/sizes on smoke emission rates, we have developed direct linear relationships between the MODIS-measured R_{fre} and smoke aerosol emission rates R_{sa} (in kilograms per second), derived by analyzing MODIS measurements of aerosol spatial distribution around the fires with National Center for Environmental Prediction/National Center for Atmospheric Research wind fields. We applied the technique to several regions around the world and derived a FRE-based smoke emission coefficient, C_e (in kilograms per megajoule), which can be simply multiplied by R_{fre} to calculate R_{sa}. This new coefficient C_e is an excellent remote sensing parameter expressing the emission strength of different ecosystems and regions. Analysis of all 2002 MODIS data from Terra and Aqua satellites yielded C_e values of 0.02–0.06 kg/MJ for boreal regions, 0.04–0.08 kg/MJ for both tropical forests and savanna regions, and 0.08–0.1 kg/MJ for Western Russian regions. These results are probably overestimated by about 50% because of uncertainties in some of the data, parameters, and assumptions involved in the computations. This 50% overestimation is comparable to uncertainties in traditional emission factors. However, our satellite method shows great promise for accuracy improvement, as better knowledge is gained about the sources of the uncertainties.**

***Index Terms*—Aerosol, biomass burning, fire radiative energy (FRE), Moderate Resolution Imaging Spectroradiometer (MODIS), particulate matter, smoke emission.**

I. Introduction

WILDFIRES and prescribed biomass-burning devastate vast areas of forest lands, grass lands, and agricultural lands across the globe, consuming an estimated 5500–9200 Tg of biomass annually [1], [2]. For instance, in Canada alone, it was estimated that about 4.9 million hectares burned in 1995 [3]. By so doing, fires directly exert adverse (and, in some cases, favorable) influences on ecology, population, habitat, agriculture, transportation, and security. The 2001 report of the Intergovernmental Panel on Climate Change (IPCC) [4] states that "most climate scenarios indicate that the probability of large fires will increase" (IPCC, 2001, sec 13.2.2.1.2). The effects of fires on climate and the environment are not limited to the ravages of their flame but also include the impacts of the energy, aerosols (or particulate matter, PM), and trace gases emitted into the atmosphere. Fires release heat energy, which is propagated by conduction, convection, and radiation. Fire radiative energy (FRE), like other types of electromagnetic radiant energy, propagates in space and can be sensed from aircraft and satellites. The Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor, launched aboard the Earth Observing System (EOS) Terra and Aqua satellites on December 18, 1999 and May 4, 2002, respectively, is the first to operationally measure from space the FRE rate of release (R_{fre}), using its 3.96-μm channels, which do not saturate for most fires.

Commensurate with the large volumes of biomass consumed by fires, tremendous amounts of smoke are emitted into the atmosphere annually. Globally, an estimated 3.1×10^9 t of biomass carbon is exposed to burning annually, of which 1.1×10^9 t is emitted to the atmosphere through combustion [5]. Smoke comprises aerosol particles and trace gases (including CO_2, CO, CH_4, and other species), which constitute air pollutants and contribute to the perturbation of the global radiative balance through the scattering and absorption of solar radiation. Andreae and Merlet [6] provide a detailed list of the various particulate and gaseous species emitted by fires. Although some trace gases (CO_2 and CH_4) have long been associated with climate change, atmospheric aerosols and, particularly, smoke aerosol (because of its considerable black carbon content) probably have a much greater impact, not only on climate, but also on weather, health, aviation, visibility, and environmental pollution. However, the global effects of fires and emitted smoke aerosols and trace gases are still poorly understood. To fully understand the effects of biomass burning on humans and the environment, it is important to acquire an accurate quantitative inventory of the fire locations and frequency, the amount of biomass they consume, and the energy, aerosols, and trace gases they release into the atmosphere.

Accurate assessment of the environmental and climate effects of smoke can only be achieved if the amount or the rate of emission of smoke is estimated accurately. It is a common saying that: "there is no smoke without fire." Ironically, some of the initial attempts at estimating emissions did not include any quantitative measure of the fire, but were based on limited localized smoke measurements, which were then extrapolated

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